



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification ⁶ : H01M 6/18, 6/00		A1	(11) International Publication Number: WO 95/15589 (43) International Publication Date: 8 June 1995 (08.06.95)		
(21) International Application Number: PCT/US94/12641 (22) International Filing Date: 2 November 1994 (02.11.94)		(81) Designated States: CA, CN, JP, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).			
(30) Priority Data: 08/160,018 30 November 1993 (30.11.93) US		Published <i>With international search report.</i>			
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(54) Title: ELECTROLYTE ACTIVATABLE LITHIUM-ION RECHARGEABLE BATTERY CELL AND METHOD OF MAKING SAME					
(57) Abstract					
<p>Li-ion rechargeable battery cell electrode (13, 17) and electrolyte/separator (15) elements formulated as layers of plasticized polymeric matrix compositions are laminated to form a unitary battery cell structure. The structure may be stored indefinitely, since it is essentially devoid of electrolyte solution which typically comprises a moisture-sensitive lithium salt. Prior to the battery's being put into service, the plasticizer of the polymeric composition is removed by extracting with a selective solvent and is replaced with a lithium salt electrolyte solution by simple imbibition. The battery thus activated may then be charged and recharged in the usual manner.</p>					

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ELECTROLYTE ACTIVATABLE LITHIUM-ION
RECHARGEABLE BATTERY CELL AND METHOD OF MAKING SAME

5

BACKGROUND OF THE INVENTION

The present invention relates to electrolytic cells
10 comprising polymeric film composition electrodes and separator
membranes and to a method of economically making such cells. In
particular, the invention relates to rechargeable lithium
battery cells comprising an intermediate separator element
containing an electrolyte solution through which lithium ions
15 from a source electrode material move between cell electrodes
during the charge/discharge cycles of the cell. The invention
is particularly useful for making such cells in which the ion
source electrode is a lithium compound or other material
capable of intercalating lithium ions, and where an electrode
20 separator membrane comprises a polymeric matrix made ionically
conductive by the incorporation of an organic solution of a
dissociable lithium salt which provides ionic mobility.

In our earlier investigations (U.S. Patent 5,296,318),
25 strong, flexible polymeric electrolytic cell separator membrane
materials were discovered which readily retain electrolyte
lithium salt solutions and remain functional over temperatures
ranging well below room temperature. These electrolyte
membranes were employed either in the usual manner as separator
30 elements with mechanically assembled battery cell components or
in composite battery cells constructed of successively coated

layers of electrode and electrolyte compositions. In each of these implementations, however, the polymeric electrolyte/separator elements often contained the lithium electrolyte salts at the time of cell assembly and, due to the hygroscopic 5 nature of those salts, thus necessitated extraordinary environmental conditions during cell assembly.

The present invention provides a manner of utilizing these improved polymeric electrolyte membrane and electrode 10 compositions which substantially eliminates the need for special environmental controls during cell manufacture. Further, the present battery structure with its bonded layers requires less electrolyte, which in previous battery 15 constructions was in part wasted in large voids, thereby yielding a more economical and versatile battery cell product.

SUMMARY OF THE INVENTION

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Electrolytic cell electrode and separator elements utilizing polymeric materials according to the present invention comprise the combination of a poly(vinylidene fluoride) copolymer matrix and a compatible organic solvent 25 plasticizer which maintains a homogeneous composition in the form of a flexible, self-supporting film. The copolymer comprises about 75 to 92% by weight vinylidene fluoride (VdF) and 8 to 25% hexafluoropropylene (HFP), a range in which the latter co-monomer limits the crystallinity of the final 30 copolymer to a degree which ensures good film strength while enabling the retention of about 40 to 60% of preferred solvents

for lithium electrolyte salts. Within this range of solvent content, the 5 to 7.5% salt ultimately comprising a hybrid electrolyte membrane yields an effective room temperature ionic conductivity of about 10^{-4} to 10^{-3} S/cm, yet the membrane 5 exhibits no evidence of solvent exudation which might lead to cell leakage or loss of conductivity.

Electrolytic cells, such as rechargeable battery cells, are constructed according to the invention by means of the 10 lamination of electrode and electrolyte cell elements which are individually prepared, by coating, extrusion, or otherwise, from compositions comprising the noted PVdF copolymer materials. For example, in the construction of a lithium-ion battery, a current collector layer of aluminum foil or grid is 15 overlaid with a positive electrode film or membrane separately prepared as a coated layer of a dispersion of intercalation electrode composition, e.g., a LiMn_2O_4 powder in a copolymer matrix solution, which is dried to form the membrane. An electrolyte/separator membrane formed as a dried coating of a 20 composition comprising a solution of the VdF:HFP copolymer and a plasticizer solvent is then overlaid upon the positive electrode film. A negative electrode membrane formed as a dried coating of a powdered carbon dispersion in a copolymer matrix solution is similarly overlaid upon the separator membrane 25 layer, and a copper collector foil or grid is laid upon the negative electrode layer to complete the cell assembly. This assembly is then heated under pressure to achieve heat-fused bonding between the plasticized copolymer matrix components and to the collector grids to thereby effect the lamination of the 30 cell elements into a unitary flexible battery cell structure.

At this stage the laminated structure comprises a significant measure of homogeneously distributed organic plasticizer solvent, particularly in the separator membrane stratum, yet is devoid of hygroscopic electrolyte salt. As a 5 result, the "inactive" battery cell may be stored at ambient conditions, either before or after being shaped or further processed, without concern for electrolyte deterioration due to reaction with atmospheric moisture. Only during the final sealing operation when an electrolyte salt solution is 10 introduced to activate the battery cell need there be concern for maintaining anhydrous conditions, as may be effectively achieved in an atmosphere of dry, inert gas.

When it is desired to so activate a battery in the final 15 stage of manufacture, the laminate cell structure is immersed in or otherwise contacted with an electrolyte salt solution which will imbibe into the VdF:HFP copolymer membrane matrix to provide substantially the same ionic conductivity enhancement as achieved by a preformed hybrid electrolyte/separator film 20 containing such an electrolyte salt solution. In order to facilitate the absorption of electrolyte solution, it is preferred that a substantial portion of the plasticizer solvent be previously removed from the copolymer matrix. This may be readily accomplished at any time following the laminating 25 operation by immersion of the cell laminate in a copolymer-inert, low-boiling solvent, such as diethyl ether or hexane, which will selectively extract the plasticizer without significantly affecting the copolymer matrix of the cell element strata. The extracting solvent may then be simply 30 evaporated to yield a dry, inactive battery cell.

The battery structures of the present invention may be successfully activated with any of the numerous compositions used as liquid electrolyte solutions. Notably, there may be employed in the electrolyte solution such organic solvents as

5 dimethyl carbonate, diethoxyethane, diethyl carbonate, dimethoxyethane, and dipropyl carbonate. Also, in the formulation of the activating electrolyte solutions, other useful lithium salts, including LiClO_4 , $\text{LiN}(\text{CF}_3\text{SO}_2)_2$, LiBF_4 , LiCF_3SO_3 , and LiSbF_6 , may be employed in solution concentrations

10 of between about 0.5 and 2M. Of particular utility are the exceptional ethylene carbonate/dimethyl carbonate compositions of LiPF_6 and mixtures with LiBF_4 described in U.S. Patent 5,192,629.

15 The battery-forming process of the present invention is readily adaptable to batch or continuous operation, since the electrode and electrolyte/separator membrane elements, as well as the collector grid foils, may be shaped or sized prior to laminate assembly or they may be laminated from confluent webs

20 of membrane materials for later shaping or manifolding, as desired. The extraordinary advantage of the present invention lies in the fact that all such operations may be carried out at ambient conditions prior to the introduction of any vulnerable electrolyte salts.

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BRIEF DESCRIPTION OF THE DRAWING

The present invention will be described with reference to
5 the accompanying drawing of which:

FIG. 1 is a diagrammatic representation of a typical
laminated lithium-ion battery cell structure of the present
invention;

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FIG. 2 is a graph of the capacity of a laminated lithium-
ion battery cell of FIG. 1 as a function of the number of
charge/discharge cycles;

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FIG. 3 is a diagrammatic representation of a laminating
process for preparing a battery cell structure of the present
invention; and

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FIG. 4 is a diagrammatic representation of a multicell
battery cell structure of the present invention.

DESCRIPTION OF THE INVENTION

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A laminated rechargeable battery cell structure of the
present invention as depicted in FIG. 1 comprises a copper
collector foil 11, preferably in the form of an open mesh grid,
upon which is laid a negative electrode membrane 13 comprising
30 an intercalatable material, such as carbon or graphite, or a
low-voltage lithium insertion compound, such as WO_2 , MoO_2 , or

Al, dispersed in a polymeric binder matrix. An electrolyte/separator film membrane 15 of plasticized VdF:HFP copolymer is positioned upon electrode element 13 and is covered with a positive electrode membrane 17 comprising a composition of a 5 finely-divided lithium intercalation compound, such as LiMn₂O₄, LiCoO₂, or LiNiO₂, in a polymeric binder matrix. An aluminum collector foil or grid 19 completes the assembly which is then pressed between platens (not shown) under heat and pressure to soften and bond the polymeric components and laminate the 10 membrane and grid layers.

Separator membrane element 15 is generally prepared from a composition comprising the earlier-noted 75 to 92% vinylidene fluoride:8 to 25% hexafluoropropylene copolymer (available 15 commercially from Atochem North America as Kynar FLEX) and an organic solvent plasticizer. Such a copolymer composition is also preferred for the preparation of the electrode membrane elements, since subsequent laminate interface compatibility is ensured. The plasticizing solvent may be one of the various 20 organic compounds commonly used as solvents for electrolyte salts, e.g., propylene carbonate or ethylene carbonate, as well as mixtures of these compounds. Higher-boiling plasticizer compounds, such as dibutyl phthalate, dimethyl phthalate, diethyl phthalate, and tris butoxyethyl phosphate are 25 particularly suitable. Inorganic filler adjuncts, such as fumed alumina or silanized fumed silica, may be used to enhance the physical strength and melt viscosity of a separator membrane and, in some compositions, to increase the subsequent level of electrolyte solution absorption.

Any common procedure for casting or forming films or membranes of polymer compositions may be employed in the preparation of the present membrane materials. Where casting or coating of a fluid composition is used, e.g., with meter bar or 5 doctor blade apparatus, the viscosity of the composition will normally be reduced by the addition of a readily evaporated casting solvent, such as tetrahydrofuran (THF), acetone, or the like. Such coatings are normally air-dried at moderate temperature to yield self-supporting films of homogeneous, 10 plasticized copolymer compositions. A membrane material, particularly for use as a separator element, may also be formed by allowing the copolymer in commercial form, i.e., bead or powder, to swell in a proportionate amount of plasticizer solvent and then pressing the swollen mass between heated 15 (e.g., about 130°C) plates or rollers, or extruding the mixture.

Lamination of assembled cell structures may similarly be accomplished by commonly-used apparatus. Preshaped or sized assemblies may be simply pressed for a short while between metal 20 plates weighted at about 3×10^4 to 5×10^4 Pa in an oven at a temperature of about 120° to 160°C. Where continuous webs of component membranes are available, the operation may be carried out using heated calendar rollers.

25 Subsequent to lamination, the battery cell material may be stored under normal conditions, either with the retained plasticizer or as a "dry" sheet after extraction of the plasticizer with a selective low-boiling solvent, for any length of time prior to final battery processing and 30 activation. The laminate may be die-punched into coins for use in the familiar "button" batteries or elongated sheets of the

flexible laminated cell material may be rolled with an interposed insulator or manifolded to yield a compact, high-density structure to be sealed with activating electrolyte solution in a protective enclosure.

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Although a plasticized copolymer matrix, particularly that of the separator stratum, will readily imbibe an electrolyte salt solution which, in effect, displaces the plasticizer solvent, it is preferable to extract the 10 plasticizer to facilitate absorption of the fluid electrolyte. While an extracted, "dry" battery cell laminate possesses no discernible voids, it appears to exhibit a solvent recovery "memory" which prompts the rapid absorption of an amount of electrolyte solution substantially equal to that of the initial 15 plasticizer solvent. In this manner, the desired ion conductivity range of up to about 10^{-3} S/cm is readily achieved.

A number of electrolytic cell laminates with compositions comprising VdF:HFP copolymers within the noted monomer ratio 20 range were prepared and tested for electrolytic and physical suitability for use in rechargeable batteries cells. The following examples are illustrative of such preparation and use.

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EXAMPLE 1

A coating composition was prepared by suspending 1.5 g of an 85:15 VdF:HFP copolymer of about 260×10^3 MW (Atochem Kynar FLEX 2750) in 10 g of acetone and 1.5 g of propylene carbonate 30 (PC). The mixture was warmed to about 50°C to facilitate dissolution and with occasional agitation a solution was

obtained which retained its fluidity upon standing at room temperature for a number of hours. The solution was cast upon a glass plate with a doctor-blade device gapped at about 1.5 mm and was allowed to dry in air at room temperature for about 10 minutes. The resulting dry, clear, tough, flexible film was readily removed from the glass substrate and was divided into test samples. A few samples were completely extracted with diethyl ether to remove the homogeneously dispersed PC plasticizer solvent which was then calculated to be present in the original samples at a level of about 47.7% by weight. Such a film with retained plasticizer solvent (PC) represents the "wet" form of polymeric electrolyte/separator membrane material which may be stored for later convenient assembly with cell electrode elements. The test sample films from which the PC had been extracted represents the "dry" form of the membrane material.

EXAMPLE 2

20 A control film material was prepared as in Example 1 with the exception that the PC plasticizer solvent was not added. The resulting film was clear, tough, and flexible, although, understandably, not as extensible as the plasticized sample. Samples of the "wet", "dry", and control films were immersed for 25 a few minutes in a typical rechargeable lithium battery electrolyte solution, viz., a 1 M solution of LiPF₆ in a 1:1 mixture of ethylene carbonate and propylene carbonate (EC/PC). The samples were then wiped to remove any surface accumulation of electrolyte solution, weighed, and extracted with PC and 30 diethyl ether, in turn, to remove imbibed electrolyte solution. It was then calculated that the control sample absorbed about

27% electrolyte solution, while the preswollen "wet" sample took up about 47%, a nearly complete substitution for the original amount of the PC plasticizer in the membrane before immersion in electrolyte. The remaining "dry" sample, that from 5 which the original PC plasticizer had been extracted, absorbed about 37% electrolyte solution, nearly 40% more than the control sample. This increase in absorption capacity is indicative of the swelling "memory" imparted to the film by the initial plasticizer solvent content. The ionic conductivity of 10 the membrane samples thus swollen by immersion in electrolyte solution were tested for conductivity according to the usual ac impedance method on common test equipment, e.g., a Hewlett-Packard computer-controlled HP4192A capacitance bridge operating over the frequency range of 5 Hz to 10 MHz. The "wet", 15 "dry", and control film samples exhibited ionic conductivities of about 3×10^{-4} , 9×10^{-5} , and 5×10^{-5} S/cm, respectively.

EXAMPLE 3

20 Test samples were prepared in the manner of Example 2 with substitution of dibutyl phthalate (DBP) for the PC plasticizer solvent. The absorption of electrolyte by the "wet" and "dry" samples during immersion increased significantly over the PC samples, amounting to about 65% and 45%, respectively. Ionic 25 conductivity of the samples increased accordingly, measuring about 2×10^{-3} and 3×10^{-4} S/cm, respectively.

EXAMPLE 4

30 Test samples according to Examples 1-3 were prepared with tetrahydrofuran (THF) instead of acetone. The results of

electrolyte absorption and ionic conductivity tests were substantially similar.

EXAMPLE 5

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Indicative of other film formation techniques which may be used, about 50 parts by weight of the 85:15 copolymer of Examples 1 were suspended, without acetone vehicle solvent, in an equal amount by weight of dibutyl phthalate and allowed to 10 swell until substantially homogeneous. The resulting swollen mass was then pressed at about 130°C for 1 min between polished aluminum plates separated by 0.15 mm shims. After cooling to room temperature, the resulting clear, flexible film sheet was readily removed from the plates. A sample section of the sheet 15 was then extracted with diethyl ether and reswollen in the electrolyte solution of Example 2 to yield an electrolyte/separator membrane retaining about 40% electrolyte solution and exhibiting an ionic conductivity of about 1×10^{-4} S/cm.

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EXAMPLE 6

An electrolyte/separator membrane coating solution was prepared by suspending 2.0 g of an 88:12 VdF:HFP copolymer of about 380×10^3 MW (Atochem Kynar FLEX 2801) in about 10 g of 25 acetone and adding to this mixture about 2.0 g of dibutyl phthalate (DBP). The completed mixture was warmed to about 50°C to facilitate dissolution and with occasional agitation a solution was obtained which retained its fluidity after standing at room temperature for a number of hours. A portion of 30 the solution was coated on a glass plate with a doctor blade device gapped at about 0.5 mm. The coated film was allowed to

dry within the coating enclosure under moderately flowing dry air at room temperature for about 10 min to yield a clear, tough, elastic membrane which was readily stripped from the glass plate. The film was about 85 μm thick with a dry basis weight of about 0.1 kg/m² and was easily cut into rectangular separator elements of about 175 x 45 mm which could be stored for days at ambient room conditions without significant weight loss.

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EXAMPLE 7

A positive electrode coating composition was prepared by homogenizing in a lid-covered stainless steel blender for about 10 min at 4000 rpm a mixture of 10.5 g of $\text{Li}_{1+x}\text{Mn}_2\text{O}_4$, where 15 $0 < x \leq 1$ (e.g., $\text{Li}_{1.05}\text{Mn}_2\text{O}_4$ prepared in a manner described in U.S. Patent 5,196,279), sieved through 53 μm , 2.8 g of the VdF:HFP copolymer (FLEX 2801) of example 6, 4.3 g dibutyl phthalate, 1.125 g Super-P conductive carbon, and about 20 g acetone. The resulting paste was degassified by briefly 20 applying a reduced pressure to the mixing vessel, and a portion was then coated on a glass plate with a doctor blade device gapped at about 1.1 mm. The coated layer was allowed to dry within the coating enclosure under moderately flowing dry air at room temperature for about 10 min to yield a tough, elastic 25 film which was readily stripped from the glass plate. The film was about 0.3 mm thick with a dry basis weight of about 0.6 kg/m² and was easily cut into rectangular electrode elements of about 165 x 40 mm. These film elements could be stored for days at ambient room conditions without significant weight loss.

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EXAMPLE 8

A negative electrode coating composition was prepared by homogenizing in a lid-covered stainless steel blender for about 5 10 min at 4000 rpm a mixture of 7.0 g of a commercial petroleum coke (ball-milled and sieved through 53 μm), 2.0 g of the VdF:HFP copolymer (FLEX 2801) of example 6, 3.12 g dibutyl phthalate, 0.37 g Super-P conductive carbon, and about 12 g acetone. The resulting paste was degassified by briefly 10 applying a reduced pressure to the mixing vessel, and a portion was then coated on a glass plate with a doctor blade device gapped at about 0.6 mm. The coated layer was allowed to dry within the coating enclosure under moderately flowing dry air at room temperature for about 10 min to yield a tough, elastic 15 film which was readily stripped from the glass plate. The film was about 0.2 mm thick with a dry basis weight of about 0.3 kg/ m^2 and was easily cut into rectangular electrode elements of about 165 x 40 mm. These film elements could be stored for days at ambient room conditions without significant weight loss.

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EXAMPLE 9

Rechargeable battery structures may be readily assembled from component electrode and electrolyte elements prepared in 25 the manner of the foregoing examples. The conditions of electrode preparation may be varied, either in coating composition consistency or coated layer thickness, to obtain a basis weight ratio of active intercalation compound in the 30 positive:negative electrode combination between about 1.5 and 2.5, preferably about 2.2. A basic battery cell structure is depicted in FIG.1 and was assembled in the following manner:

A 180 x 40 mm copper current collector foil 11, preferably in the form of an open mesh grid of about 50 μm thickness (e.g., a MicroGrid precision expanded foil marketed by Delker Corporation), was trimmed at one end to form a tab 12 which 5 would subsequently serve as a convenient battery terminal. To enhance the ensuing adherence to its associated electrode element, grid 11 was surface-cleaned by immersing for a few seconds in a common "copper bright" solution (mixed dilute HNO_3 , H_2SO_4), rinsing in water, air drying, dip coating in a 0.5% 10 acetone solution of the VdF:HFP copolymer of Example 6, air drying, and oven heating at about 350°C for 5-10 seconds. The heating step may be eliminated by using a dip coating solution of about 3% each of VdF:HFP copolymer and dibutyl phthalate. Grid 11 was then laid smoothly upon a flat rigid base plate (not 15 shown) of a good heat conductive material, such as aluminum.

A carbon negative electrode element 13, as prepared in Example 8, was overlaid upon grid 11, and was itself overlaid with electrolyte/separator element 15, as prepared in 20 Example 6. The slightly larger dimensions of element 15 provide protection from possible misalignment and undesirable contact between the electrode elements of the assembled battery structure. Positive electrode element 17, as prepared in Example 7, was then positioned upon separator element 16, and an 25 aluminum collector foil or grid 19, treated in a manner similar to grid 11, but for a simple initial cleaning immersion in acetone, was positioned upon electrode 17 so as to provide a transversely situated terminal tab 18. It should be noted that at least one of the current collector elements preferably has an 30 open grid structure to facilitate the passage of extraction and

activating fluids during the ensuing battery preparation operations.

The resulting structure was then covered with a second 5 similar rigid plate (not shown), and the assembly was placed in a 135°C oven and weighted with about 24 kg to provide a pressure of about 3.7×10^4 Pa at the element interfaces. The assembly remained in the oven for about 30 minutes to ensure temperature equilibrium in the plate sinks and effect adequate fusion of the 10 battery elements. The laminate structure was then removed from the oven, unweighted, and cooled between a pair of room temperature metal plates. In order to ensure optimum bonding or embedding of the collector grids in a final single cell structure, about 50 μm membranes of electrolyte/separators 15 composition (not shown) may be overlaid upon the grid elements prior to lamination, or, preferably, about 20 μm coatings of the composition may be applied over the surfaces of a laminated structure.

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EXAMPLE 10

The battery structure of Example 9 was prepared for "dry" film activation, as described in Example 2, by immersion of the laminate structure in diethyl ether at room temperature for 25 about 25 minutes to remove substantially all of the DBP plasticizer from the layered elements, notably the electrolyte/separator 15. This extraction was carried out with a minimum of agitation of the immersion solvent.

30 Extraction time for similar structure samples was reduced to about 10 min with mild agitation, e.g., from stirring or

bubbling air, and was optimally reduced to about 3 minutes with continuous countercurrent processing using fresh extraction solvent. Other useful solvents include pentane, petroleum ether, hexane, and cyclohexane.

5

EXAMPLE 11

An extracted battery structure from Example 10 was activated in preparation for charge/discharge cycling by 10 immersion under a substantially moisture-free atmosphere in a 1M electrolyte solution of LiPF₆ in 50:50 ethylene carbonate (EC):dimethyl carbonate (DMC) for about 20 min during which the laminated battery imbibed about 31% of its extracted weight. Following a mild wiping with absorbent materials to remove 15 surface electrolyte, the activated battery structure was hermetically sealed, but for the extending terminal tabs 12, 18, within a polyolefin envelope (not shown) to maintain a moisture-free environment.

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EXAMPLE 12

An extracted battery structure from Example 10 was activated in preparation for charge/discharge cycling by 25 immersion in a 1M solution of LiPF₆ in 50:50 ethylene carbonate (EC):propylene carbonate (PC) for about 30 min during which the laminated battery imbibed about 28% of its extracted weight.

EXAMPLE 13

30 The activated battery of Example 11 was tested by cycling between 2 and 4.5 V at a rate of 10 mA which was maintained

constant within 1% in a "Mac Pile" cycling system from Bio-Logic of Claix, France. Operating in the galvanostatic mode, this system calculated from elapsed time and current the lithium content, x , in the $\text{Li}_x\text{Mn}_2\text{O}_4$ positive electrode. The trace of 5 cell capacity over extended charging cycles is shown in FIG. 2. Similar testing of the battery of Example 12 produced substantially similar results.

EXAMPLE 14

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In a preferred variant of the present laminate battery assembly method, as depicted in FIG. 3, a copper collector grid 41 and a negative electrode element 43, as prepared in Examples 9 and 8, were assembled between buffer sheets of abherent 15 polyethylene terephthalate (not shown) and were passed through the rolls 46 of a commercial card-sealing laminator at a temperature of about 150°C. A 50 μm film of electrolyte/separator composition may also be inserted on top of the grid prior to lamination. A treated aluminum collector grid 49 and a 20 positive electrode element 47, as prepared in Examples 9 and 7, were similarly laminated to provided a pair of electrode/collector battery elements. An electrolyte/separator element 45 from Example 6 was then inserted between the electrode/collector pair and the resulting assembly was passed through 25 the laminator device at a roll temperature of about 120°C with somewhat less pressure to obtain the laminate battery structure. The laminate was then immersed under moisture-free conditions in a mildly stirred electrolyte solution from Example 11 for about 40 minutes to effect substantial 30 replacement of the DBP plasticizer with the electrolyte solution. The activated battery, having a thickness of about

0.5 mm, was then sealed in a protective polyolefin envelope enclosure (not shown) and tested according to Example 13. The resulting performance trace substantially matched that of FIG. 2.

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EXAMPLE 15

A laminated battery structure of Example 14 was extracted of plasticizer by immersion in stirred diethyl ether for about 10 10 minutes and was then activated by immersion in electrolyte solution as described in Example 12. The battery was then heat-sealed for later testing in a close-fitting envelope of moisture-proof barrier material, such as polyolefin/aluminum foil/polyester laminate sheeting commercially used for 15 foodstuff enclosures.

EXAMPLE 16

An extracted battery structure was prepared as in Example 20 15, but, instead of being activated by immersion, was inserted directly into a similar envelope along with an amount of electrolyte solution equal to that imbibed by the immersed sample of Example 15. The envelope was then hermetically sealed for later testing. After 3 days the sample batteries were tested 25 through the usual cycling series with substantially the same results as appear in FIG. 2. As an alternative procedure, electrolyte solution may be injected into a sealed battery enclosure in a manner which substantially maintains the seal.

30

EXAMPLE 17

A multicell battery configuration as depicted in FIG. 4 was prepared in the manner generally described in Example 9, 5 with the exception that the lay-up of the copper collector 51, negative electrode 53, electrolyte/separator 55, positive electrode 57, and aluminum collector 59 battery elements was extended as shown in this FIG. Tabs 52, 58 of the collector elements form respective common terminals for the battery 10 structure. After extraction and activation according to Examples 10 and 11, the battery of about twice the capacity of the earlier sample continued to perform in the manner shown in FIG. 2. Batteries of proportionately greater capacity can readily be constructed by repeating, as desired, the sequences 15 of battery elements as desired. Consideration should, of course, be given to the anticipated increase in processing time occasioned by the increased mass of material through which extraction and activation fluids will pass.

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What is claimed is:

1. A rechargeable battery structure comprising a positive
5 electrode element, a negative electrode element, and a
separator element disposed therebetween

characterized in that
each of said elements comprises a flexible, self-supporting,
polymeric matrix film composition, and each said element is
10 bonded to contiguous elements at its respective interfaces to
form a unitary flexible laminate structure.

2. A rechargeable battery structure according to claim 1
15 wherein the separator element film comprises a composition
initially comprising a polymeric material and 20 to 70% by
weight of a plasticizer therefor and from which composition at
least a portion of said plasticizer has been removed and
replaced with a battery electrolyte solution.

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3. A rechargeable battery structure according to claim 2
wherein said separator element composition comprises a
copolymer of vinylidene fluoride with 8 to 25% by weight
25 hexafluoropropylene.

4. A rechargeable battery structure according to claim 3
wherein said separator element composition comprises 10 to 30%
30 by weight based on said copolymer of an inorganic filler
selected from fumed alumina and silanized fumed silica.

5. A rechargeable battery structure according to claim 3 wherein said positive electrode element composition comprises a lithium intercalation compound homogeneously distributed in a matrix of said separator element polymeric material.

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6. A rechargeable battery structure according to claim 5 wherein said negative electrode element composition comprises a compound selected from the group consisting of carbon 10 intercalation compounds and low-voltage lithium insertion compounds homogeneously distributed in a matrix of said separator element polymeric material.

15 7. A method of making a rechargeable battery structure which comprises arranging a negative electrode and a positive electrode with a separator element disposed therebetween

characterized in that
said separator element initially comprises a polymeric material
20 and 20 to 70% by weight of a plasticizer therefor and said method further comprises:

a) extracting at least a portion of said plasticizer from
said separator element; and
b) replacing the extracted plasticizer with a battery
25 electrolyte solution.

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8. A method of making a rechargeable battery structure which comprises arranging, in sequence, a positive current collector element, a positive electrode element, a separator element, a negative electrode element, and a negative current collector element

5 element

characterized in that

- a) each of said collector elements comprises a flexible electrically-conductive foil,
- b) each of said electrode and separator elements comprises 10 a flexible, self-supporting, polymeric matrix film composition, and
- c) said method further comprises bonding each said element 15 to contiguous elements at its respect interfaces by the application of heat and pressure to form a unitary flexible laminate structure.

9. A method according to claim 8 wherein:

- a) at least one of said collector element foils comprises an 20 open-mesh grid;
- b) said separator element composition comprises a copolymer of vinylidene fluoride with 8 to 25% by weight hexafluoropropylene and has homogeneously distributed therein 20 to 70% by weight of an organic plasticizer for said 25 copolymer;
- c) said positive electrode element composition comprises a lithium intercalation compound homogeneously distributed in a matrix of said separator element polymeric material;
- d) said negative electrode element composition comprises a 30 carbon intercalation compound homogeneously distributed in a matrix of said separator element polymeric material; and

e) said method further comprises replacing at least a portion of said plasticizer with a lithium battery electrolyte solution.

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10. A method according to claim 9 wherein:

a) said portion of plasticizer is extracted from said laminate structure; and

b) said extracted laminate structure is contacted with said electrolyte solution for a time sufficient to effect the imbibing of said solution into said extracted structure.

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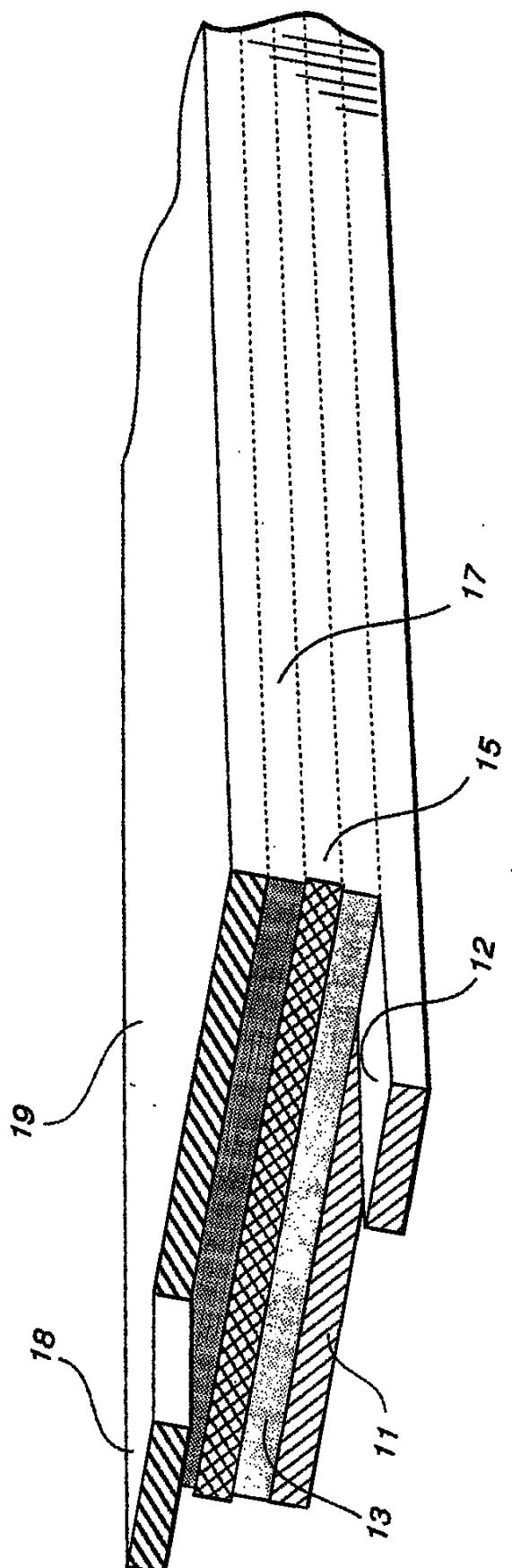


FIG. 1

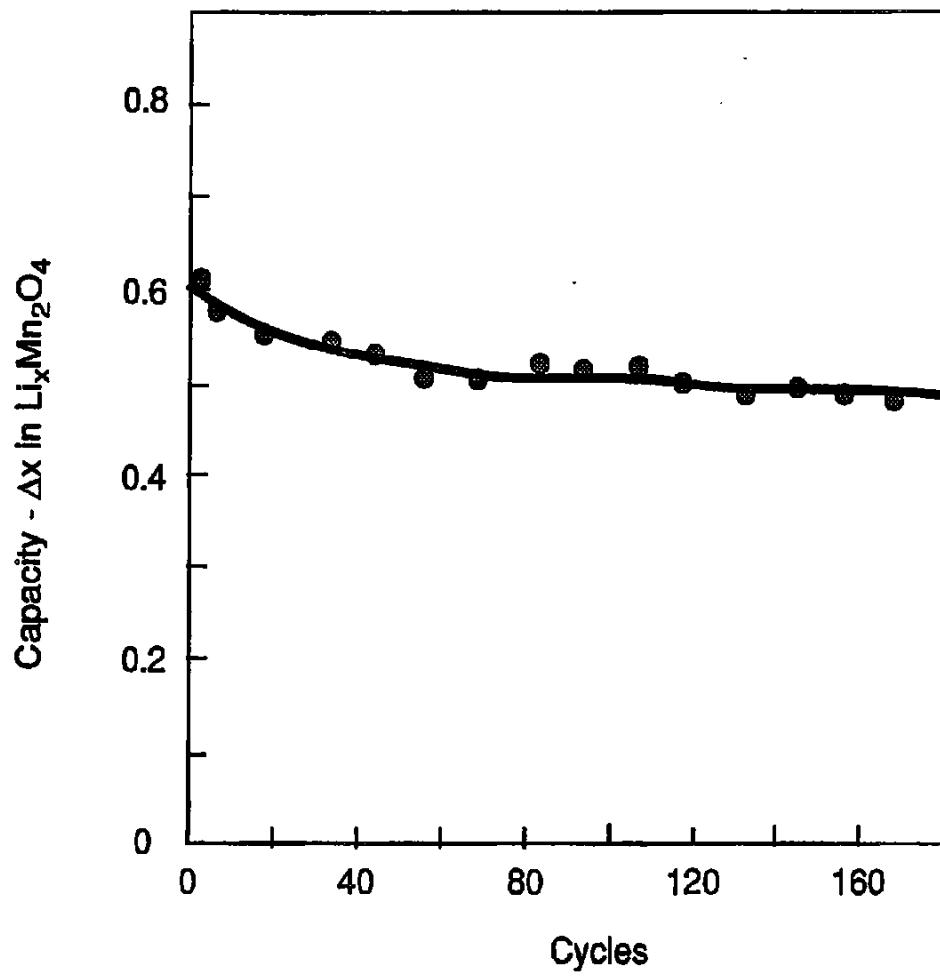


FIG. 2

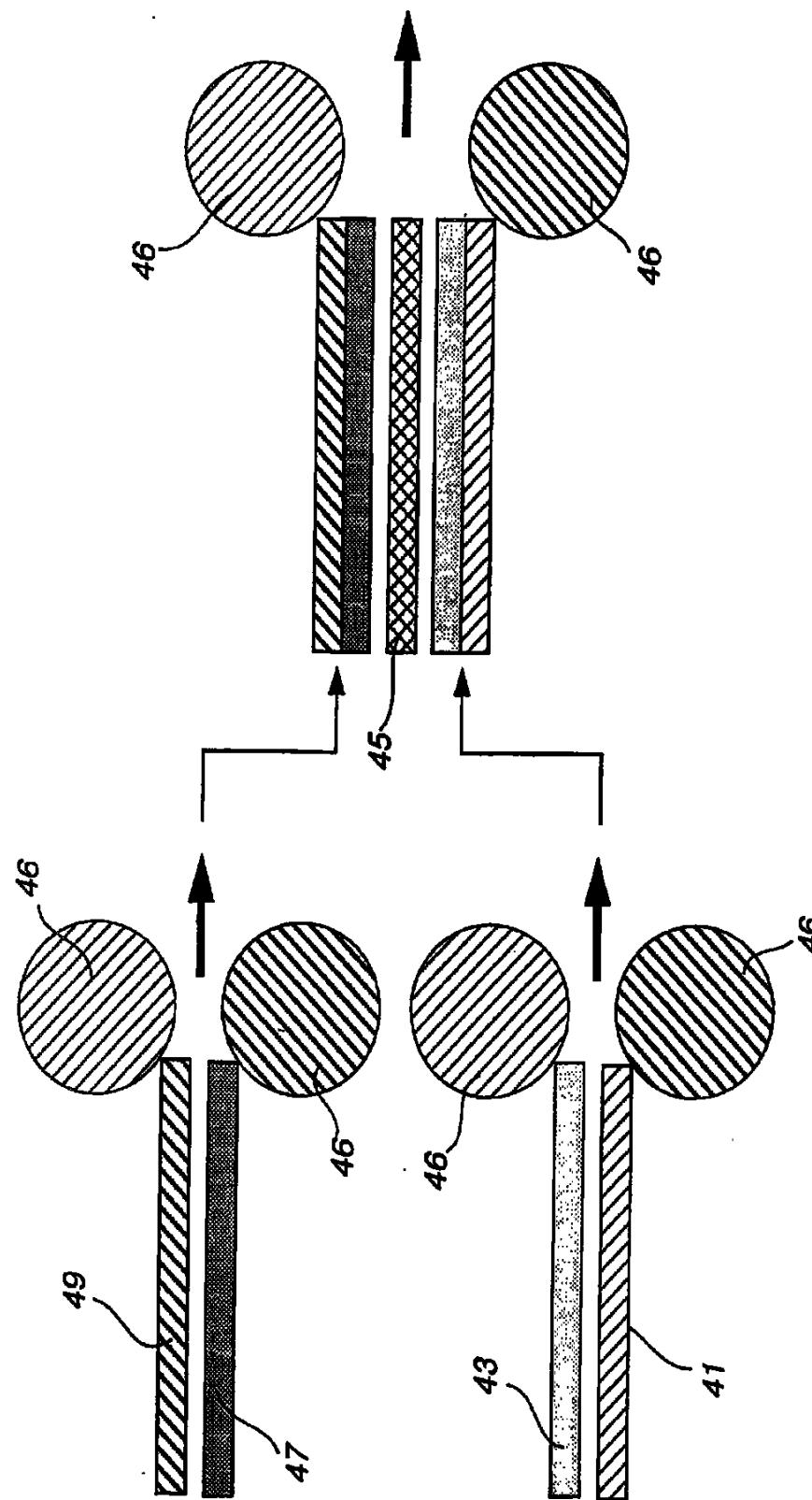


FIG. 3

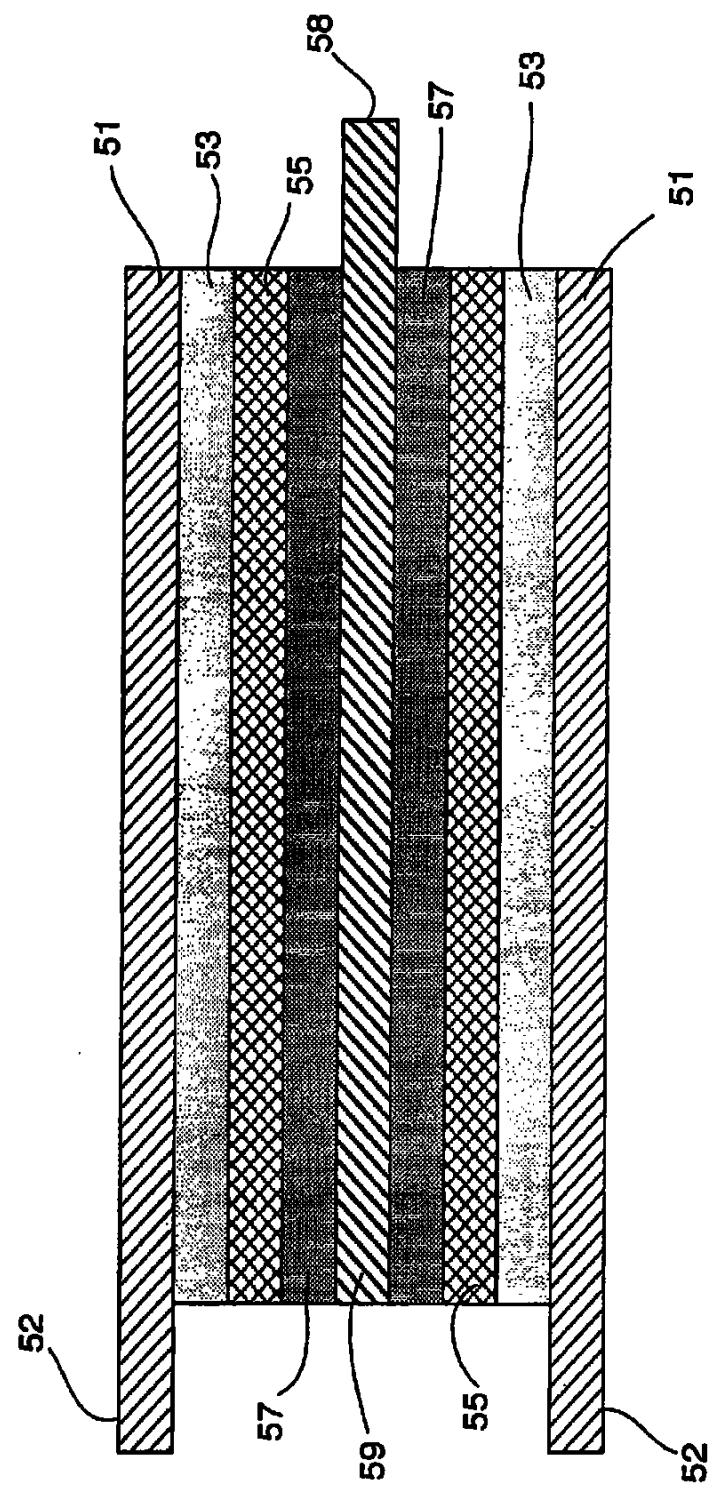


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/12641

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :H01M 6/18, 6/00

US CL :429/192; 2/623.1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 429/252, 191, 192, 194, 251, 254, 162, 127, 217; 264/344; 29/623.1, 623.5

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS

search terms: polymer, extracted, extracting, extract, plasticizer, plasticiser

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US, A, 5,219,680 (FAUTEUX) 15 June 1993, col. 5, lines 45-68.	1, 2
A	US, A, 3,351,495 (LARSEN ET AL.) 07 November 1967	
A	US, A, 4,699,857 (GIOVANNONI ET AL.) 13 October 1987	
A	US, A, 4,849,144 (McLOUGHLIN) 18 July 1989	

Further documents are listed in the continuation of Box C.

See patent family annex.

•	Special categories of cited documents:	"I"	Inter document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A"	document defining the general state of the art which is not considered to be of particular relevance	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E"	earlier document published on or after the international filing date	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L"	document which may throw doubt on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Z"	document member of the same patent family
"O"	document referring to an oral disclosure, use, exhibition or other means		
"P"	document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

17 FEBRUARY 1995

Date of mailing of the international search report

09 MAR 1995

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